Analysis and Comparison on Population Dynamics between *Adenophora lobophylla* and *Adenophora potaninii* by Leslie Matrix[1]

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Abstract The population dynamic tendency of *Adenophora lobophylla* Hong as an endangered species and *Adenophora potaninii* Korsh as widespread species, has been predicted by the Leslie matrix. And the comparison and analysis on the age structures between two species have been carried out in this paper. The results demonstrate the *A. lobophylla* populations which have the reasonable age structures perform slowly negative or positive increment at altitude 2300-3400 m. Especially, below altitude 2700 m, there are many populations performing seriously declining tendency. Contrary, *A potaninii* populations could adapt to environment perfectly at the corresponding condition without finding the population which performs the seriously declining tendency. The differences in developing tendency of population between the two species demonstrate that *A. lobophylla* populations have the weaker ability to adapt to the external unfavorable conditions.

Key words: *Adenophora lobophylla, Adenophora Potaninii*, Leslie matrix, Endangered plant population.

Introduction

The prediction of population dynamics is an important component in conservation biology of endangered plant. It could not only explain the endangered status of the plant population but also provide the scientific evidence and the guidance for making the protective plan (Jian Zhigang et al., 1997). The comparison of the population dynamic among the different populations or species could make it possible to analyze the external environmental condition and the intrinsic mechanisms which lead the population to be in endangered status (Lynch A. J. J. Et al., 1995)

Leslie matrix has been recognized to be the efficient method to forecast the plant population dynamic tendency, in which the population size at any age in the future could be forecasted. At the same time the information about birth, mortality, immigration and emigration which affect the populations growth are included in it. So far, a lot of work on the annual, perennial herbs and some long life woody species analyzed based on Leslie matrix have been reported (Grawley M., 1991; Jiang Hong, 1992; Nie Shaoquan et al., 1992). However, the studies on the population dynamics of the endangered plant species are rare, especially the comparative research work between the endangered species and the widespread species.

Adenophora lobophylla, a typical endangered plant species in China has attracted more attention owing to its importance in ecology. The genetic diversity and morphological variation have been studied extensively (Ge Song et al. 1994, 1995; Hong Deyuan, 1983). The reproductive characteristics and the regulation of individual growth also have been reported (Zu Yuangang et al. 1997; Zhang Wenhui et al., 1998). Aims of this paper are: (1). to predict the population dynamic tendencies of the whole population and other different populations at various altitudes; (2). to show the changs in pattern of numbers at different age stage; (3). to analyze the differences and population dynamic between *A. lobophylla* and *A. potaninii* .

Materials and Methods

Leslie matrix is based on the corresponding life table and the fecundity schedules (Pielou, E. C. 1977; Grawley M. 1991; Silvertown J.W. 1982; Jiang Hong, 1992). In this paper, the same method was used.

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The current population age structure at time t_0 is given by the following vector, $N_0 = (n_0\ n_1\ n_2\ n_k)$

n_0 = the number of seedlings at one year old.

n_1= the number of seedlings at 2 years old.

n_2 = the number of individuals at 3 years old. ...

n_k= the number of individuals at k+1 years old (k+1= the age of the oldest individual).

Making use of the current number of seedling of one year old and the surviving possibility (survival rate) from one age stage to next, the projection matrix was built up, M=

$$\begin{vmatrix} f_0 & f_1 & f_2 & f_3 & \cdots & f_{k-1} & f_k \\ S_0 & 0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & S_1 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & S_2 & 0 & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & 0 & S_{k-1} & 0 \end{vmatrix}$$

In this matrix,

$S_x = l_{x+1}/l_{x+0} = (l_{x+1}+l_{x+2})/(l_{x+0}+l_{x+1})$

Where S_x: the survival rate from age x to age x+1;

l_{x+0}, l_{x+1}, l_{x+2} ;the mean number of survivors during age x+0, x+1 and x+2 respectively which is from the statistic of the individual number at same age (it is from the corresponding life table), (discussed in other paper).

f_x: the number of offspring (seedling at one year old) produced by the mother individuals in the corresponding age stage, which is from the corresponding the fecundity schedules (discussed in other paper).

With the current population age structure described by the column vector at given time (t_0) and the projection matrix above, we could calculate population age structures in the future, N_1, N_2... N_k, after one unit time (year) t_1, t_2...t_k .

$N_1 = M\times N_0 \qquad N_2=M\times N_1 \ \ldots \quad N_k=M\times N_{(k-1)}$

where the subscript of N denotes the population age structure after the unit time (year) have elapsed.

A program was compiled by the Basic language. The population dynamic tendencies of different *A. lobophylla* and *A. potaninii* populations at various altitudes have been obtained finally.

A. lobophylla is a perennial herb, living in the drought-enduring shrub or herbaceous communities. It distributes only in the drought valley, on the east boundary on Tibet Plateau, Jinchuan County(31° 8'~31°58' N, and 101° 13'~102° 19' E) in Sichuan Province. The all area is not more than 5000 km^2 (Zhang Wenhui, 1998).

A. potaninii, an affinity to *A. lobophylla*, is generally recognized as a stable and extensive distributed species, because it range from the northeast, the northwest to the southwest of China(42°~26° N, 95°~125° E) (Ge Song, 1994;1995), and it does not involve in the endangered problem. In order to compare clearly with *A. lobophylla* we just selected Markang county as its investigating place where is adjacent to Jinchuan County. In 1950's, *A.obophylla* also distributed there. So, in this research, the so-call populations of *A. potaninii* actually distribute in Markang County (31° 35'~32° 24'N, 101° 17'~102° 41' N).

This area, below altitude 2400 m, belongs to warm temperate monsoon climate, with clear drought season (November-April) and raining season (May-October) where the mean annual rainfall is 616.2 mm. And the mean annual temperature is 12.8 °C. Between the altitudes 2400~3000 m, the area belongs to temperate monsoon climate, where the mean annual rainfall is 763 mm, and the mean annual temperature is 7.6 °C. Between altitudes 3000~4000 m, the area is cold temperate monsoon climate where the mean annual rainfall is 914.3 mm, and the mean annual temperature is 3.3 °C.

There are a few kinds of soil between altitudes 2200-3400 m in this area, which are mainly hilly drab soil, hilly brown soil and dark brown soil, in which pH value is 6.3~7.7, the organic material content is 2.8%~8.2 %, the soil moisture is 6.5%~23% according to 50 sample plots which we investigated.

Between altitudes 2000~2600 m., the vegetation is mainly composed by xero-spur-bush and xero-herb communities. Between altitudes 2500~3400 m, it is sub-high mountain conifer-broad mixed forest; altitudes 3400~4000 m, sub-high mountain conifer forest; altitudes 4000~4400 m, high mountain grassy marshland. *A. lobophylla* lives in those different communities from altitude 2300 m to 3400 m, and *A. potaninii* ranges from 2600 m to 3500 m.

During studying process, the same methods to deal with the data from the indoor or filed investigation for two species were adopted. 29 sample plots of *A. lobophylla* were disposed on different altitudes from 2300 m (the low limit) to 3400 m (the high limit), and 21 sample plots of *A. potaninii* from 2600 m (the low limit) to 3500 m (the high limit). Every difference of altitude 100 m there are about 2 plots.

The age of mother individual of *A. lobophylla and A. potaninii* were identified by the bud scar on the perennial corona. The number of seedlings at one year old (f_x) which the mother individuals at different ages produce were obtained from measurement on the individual samples from field condition. For every sample plot, 3 normal and middle mother individuals at every age interval were selected to determine the number of fruit,

flowers, flower buds at specific age in order to determine the number of mature seeds (B_x). The probability (Ps) for seeds to develop to be the seedlings at one year old were estimated by the all number of seeds produced by all mother individuals and the all number of seedlings at one year old in the plot. The number of the seedling at one year old (f_x) which the mother individuals at every age produce was obtained by the equation: $f_x = B_x \times Ps$.

Results and Discusses

Age structures and dynamic tendencies of *A. lobophylla* populations

The whole *A. lobophylla* population Table 1 shows the Leslie matrix and population dynamic age structure of the whole *A. lobophylla* population in the future. In the projection matrix, the first row is the numbers of offspring (f_x, seedling at one year old) produced by mother individuals at the corresponding ages, which is from fecundity schedules of the whole population, and the numbers on the sub-diagonal is the survival rate from age x to age x+1, which is from the life table of the whole population. The column vector, $N_0$is the current age structure of the whole population, the numbers of individual at different ages in 100 m^2, which we investigated in the field condition. The column vectors, N_1, N_2, N_3, N_4, N_5 indicate the population age structures predicated respectively.

Table 1. Leslie matrix(M) and changes in age structure (N) of population of *A. lobophyilla* between altitudes 2300-3400 m.

$$M=\begin{bmatrix}
0.000 & 0.028 & 0.076 & 0.273 & 0.365 & 0.373 & 0.427 & 0.573 & 0.680 & 1.111 & 1.156 & 1.482 & 1.256 & 0.972 & 0.437 \\
0.600 & & & & & & & & & & & & & & \\
& 0.658 & & & & & & & & & & & & & \\
& & 0.829 & & & & & & & & & & & & \\
& & & 0.802 & & & & & & & & & & & \\
& & & & 0.814 & & & & & & & & & & \\
& & & & & 0.940 & & & & & & & & & \\
& & & & & & 0.879 & & & & & & & & \\
& & & & & & & 0.854 & & & & & & & \\
& & & & & & & & 0.923 & & & & & & \\
& & & & & & & & & 0.855 & & & & & \\
& & & & & & & & & & 0.712 & & & & \\
& & & & & & & & & & & 0.475 & & & \\
& & & & & & & & & & & & 0.283 & & \\
& & & & & & & & & & & & & 0.500 & 0.000
\end{bmatrix}$$

$N=$

Age	Different generation after 1-5 years					
	N_0	N_1	N_2	N_3	N_4	N_5
1	40	40	39	39	39	39
2	25	24	24	23	23	23
3	14	16	16	16	15	15
4	11	12	13	13	13	13
5	10	9	10	11	10	10
6	7	8	7	8	9	9
7	7	7	8	7	7	8
8	6	6	6	7	6	6
9	5	5	5	5	6	5
12	5	5	5	5	5	5
15	5	4	4	4	4	4
18	3	3	3	3	3	3
21	2	2	2	1	1	1
23	1	1	1	1	1	1
25	1	1	1	1	1	1
Total number	143	142	143	144	145	146

Note In the project matrix, the number of the offsprings at one year old which were produced by mothers individuals at the corresponding age from 1 to 25 years old were shown on the first row; the survival rate from one age to next at the corresponding age stages were shown on the sub-diagonal. In the column vectors, N_0 indicates the current age structure, and N_1, N_2, N_3, N_4 and N_5 indicate the age structures after the 1st to 5th generations (year) respectively and total numbers of individuals, where $N_1=M\cdot N_0$, $N_2=M\cdot N_1$, ... $N_5=M\cdot N_4$.

The whole population of *A. lobophylla* seems to be slowly increasing with the small oscillation. In the future, the total number of population show the developing pattern which is at first decreasing and then increasing slowly. From N_0 to N_5 the total number of population is 143, 142, 143, 144, 145, 146 respectively per 100 m^2. At the same age in the different generations, the number of individuals also oscillates to some extent. For example, the number of individual at one year old, from N_0 to N_1, is 40/100 m^2, from N_2 to N_5, 39/100 m^2 for 2 years old, the number of individual reducing slowly, from 25/100 $m^2(N_0)$ to 24/100 m^2 (N_1, N_2) to 23/100 m^2 (N_3, N_4, N_5).

The whole *A. lobophylla* population including all the sample plots (29) which we have investigated in the field condition from altitude 2300 m to 3400 m represents the basic characteristics of all populations at different habitats.

The populations at different altitudes In the same way, we obtained the result predicated at different altitudes by Leslie matrix. The alteration of the number of populations is obviously connected with the habitat. In the favorable condition the population number of *A. lobophylla* performs evidently increasing tendency. For instance, the increment rate of two populations at altitudes 2700-2900 m, 2900-3100 m reached from 1.11% to 3.16% per generation without negative increment (Table 2). On the other hand, under the harsh or the serious external disturbance conditions, the populations perform the slow increment or decrement. The population at altitudes 3100-3400m performs the overall negative increment, from -1.45% to -3.95% per generation, because on the uppermost limited boundary of the *A. lobophylla* population distribution, the environment condition is hard for the population to survive. The population at altitudes 2300-2400 m performs the slow increment, from 0.25% to 1.01% per generation, because it is suffered from the serious external disturbance from human being. The number oscillations of different populations is various. The wave of population increment at altitudes 2300-2400 m is small and stable; whereas these at altitudes 2700-2900 m, 2900-3100 m increment is big and rapid. The population at altitudes 3100-3400 m performs the overall decrement with big wave (Table 2).

Table 2. The result predicted by Leslie matrix of *A. lobophylla* population.

Population distribution alt. (m)		Different generation					
		N_0	N_1	N_2	N_3	N_4	N_5
2300-3400	TNOI	143	142	143	144	145	146
(Total population)	Increment rate %		-0.70	0.70	0.70	0.69	0.69
2300-2400	TNOI	392	395	398	402	404	405
	Increment rate %		0.76	0.75	1.01	0.50	0.25
2700-2900	TNOI	237	244	250	254	260	265
	Increment rate %		2.95	2.46	1.60	2.36	1.92
2900-3100	TNOI	353	361	365	373	380	392
	Increment rate %		2.27	1.11	2.19	1.88	3.16
3100-3400	TNOI	152	146	143	140	138	136
	Increment rate %		-3.95	-2.05	-2.10	-1.43	-1.45

Note: The distributive altitude of the different populations (population distribution alt. (m)) and the total number of individuals at the different generations (TNOI)of each population with their increment (%), which is compared with the generation before it has been shown. N_0 indicates the current age structure, and N_1, N_2, N_3, N_4 and N_5 indicate the 1st, 2nd, 3rd, 4th and 5th generations, respectively

It is necessary to explain that below altitude 2700 m except some specific habitats (for example, at altitudes 2300 –2400 m above mentioned) where there are good water condition because of lower part of valley) most populations perform serious declining age structure which can not meet the requirement of the life time and fecundity schedule because the drought and disturbance from human being, therefore, we have not predicted tendency of these population by Leslie matrix . However, when we evaluate the endangered status of *A. lobophylla* population we should consider this problem.

It is clear the external environmental factors play an important role in the population dynamic tendencies. The oscillation of population is the result from the comprehensive interaction between viability of population and environmental condition.

Comparing *A. lobophylla* populations with these of *A. potaninii* population

In the same method, the age structures and the population developing tendencies of the whole population and five different populations of *A. potaninii* at altitude

2600-3500 m have been predicted by the Leslie matrices (Table 3, Table 4). In order to explain the endangered status of *A. lobophylla* population, the characteristics between two species of the whole populations and pairs of populations at the corresponding altitudes have been analyzed respectively.

The whole population of *A. potaninii* including 21 sample plots, which we have investigated, could represent the basic characteristics of populations in different habitant in this region. The forecasting results show the whole *A. potaninii* population performs the overall increment, from 1.78% to 2.91% per generation on the total number in the future (Table 3, Table 4). In the current age structure of the whole *A. potaninii* population there are 1960 individuals / 100 m^2, after 5 years, there will be 2212/100 m^2. It is clear that the *A. potaninii* population shows the far stronger increasing tendency, comparing with the whole *A. lobophylla* population which increases from -0.7% to 0.7%.

Table 3. Leslie matrix (*M*) and dynamic age structure(*N*) of whole *A. potaninii* population at altitude of 2600-3500 m.

$$M=\begin{vmatrix}
0.000 & 0.125 & 0.214 & 0.960 & 1.504 & 1.772 & 2.170 & 3.212 & 4.473 & 8.249 & 10.016 & 6.345 & 3.767 & 2.908 \\
0.449 & 0.530 & & & & & & & & & & & & \\
 & & 0.599 & & & & & & & & & & & \\
 & & & 0.908 & & & & & & & & & & \\
 & & & & 0.689 & & & & & & & & & \\
 & & & & & 0.513 & & & & & & & & \\
 & & & & & & 0.764 & & & & & & & \\
 & & & & & & & 0.740 & & & & & & \\
 & & & & & & & & 0.669 & & & & & \\
 & & & & & & & & & 0.525 & & & & \\
 & & & & & & & & & & 0.535 & & & \\
 & & & & & & & & & & & 0.529 & & \\
 & & & & & & & & & & & & & \\
 & & & & & & & & & & & & 0.111 & 0.000
\end{vmatrix}$$

$N=$

Age	Different generation after 1-5 years					
	N_0	N_1	N_2	N_3	N_4	N_5
1	946	975	968	995	1020	1051
2	387	432	437	434	446	457
3	219	205	229	232	230	236
4	102	131	123	137	139	138
5	89	93	119	112	125	126
6	85	62	64	82	77	86
8	35	44	32	33	42	39
10	27	27	33	24	25	32
12	20	20	20	25	18	19
16	9	8	7	7	7	9
18	4	5	4	4	4	4
20	3	2	2	2	2	2
21	0	1	0	0	0	0
Total.number	1960	2017	2053	2100	2151	2212

Note: In the project matrix, the numbers of offspring at one years old which were produced by mother individuals at the corresponding age from 1 to 21 years old were shown in the first row; the survivor rate from one age stage to next at the corresponding age stages were shown on the sub-diagonal. In the column vectors, N_0 indicates the current age structure, and N_1, N_2, N_3, N_4, N_5 indicate the age structures after the lst, 2nd, 3rd, 4th and 5th generation (year) respectively and the total numbers of individual (total number) ($N_1=M\times M_0$; $N_2=M\times N_1$ ... $N_5=M\times N_4$)

The different *A. potaninii* populations at altitudes 2600-2800 m, 2800-2900 m, 2900-3100 m, 3100-3300 m and 3300-3500 m all increase at varying level without finding the obviously declining population. Even at altitudes 2600-2800 m where there are the strong external disturbance from human being, and at altitude 3300-3500 m where it is the uppermost boundary for *A. potaninii* population to distribute, the both populations still perform increasing characteristics. Although two populations at altitude 2900-3100 m, 3100-3300 m

perform the little decrement in some years, they perform the slow increment finally. This situation show that the number dynamics of *A. potaninii* population are not susceptive to the external stress of environmental condition. Contrary, for *A. lobophylla* populations, below altitude 2700 m or above 3100 m, the age structures of most populations show the serious declining tendency. It is clear that the number dynamics of *A. lobophylla* population are more sensitive to the external stress of environment conditions.

Table. 4 The *A. potaninii* population predicted by Leslie matrix.

Population distribution alt. (m)	Different generation	N_0	N_1	N_2	N_3	N_4	N_5
2600-3500 (Total population)	TNOI	1960	2017	2053	2100	2125	2212
	Increment rate %		2.91	1.78	2.29	2.43	2.84
2600-2800	TNOI	1417	1455	1489	1507	1534	1569
	Increment rate %		2.68	2.34	1.21	1.79	2.28
2800-2900	TNOI	3209	3251	3291	3350	3383	3432
	Increment rate %		1.31	1.23	1.79	0.99	1.45
2900-3100	TNOI	968	989	964	946	929	931
	Increment rate %		2.17	-2.53	-1.87	-1.80	0.22
3100-3400	TNOI	3183	3116	3049	3093	3138	3220
	Increment rate %		-2.10	-2.15	1.44	1.45	4.30
3300-3500	TNOI	1292	1343	1428	1437	1458	1585
	Increment rate %		3.95	6.33	0.63	1.46	8.1

Note: The distrobutive altitude of the different populations (population distribution alt. m) and the total numbers of individuals at the different generations (TNOI) of each population with their increment rate (%), which is compared with the generation before it has been shown. N_0 indicates the current age structure, and N_1, N_2, N_3, N_4, N_5 indicate the 1st, 2nd, 3rd, 4th,5th generations respectively

Conclusion

Comparing with the extensive distribution species *A. potaninii*, most *A. lobophylla* populations, especially below altitude 2700 m, perform the declining tendency because of drought and the disturbance from human being in the natural condition. Among the 4 populations, the 2 populations at altitudes 2700-2900 m and 2900-3100 m perform developing tendency, increasing by 1.11%-3.16% per generation under the favorable conditions; the 2 populations at altitudes 2300-2400 m and 3100-3400 m which are suffered from the extremely external disturbance or the harsh environment, perform the slowly declining tendency, decreasing by -3.95% to -0.7% per generation. About *A. potaninii* populations, 3 populations at altitudes 2600-2800 m, 2800-2900 m and 3300-3500 m perform the overall increment, by 0.63%-8.71% per generation, and 2 populations at altitudes 2900-3100 m and 3100-3300 m perform the lower increment, by -2.53 % to -1.80 % per generation.

Under the similar external environmental condition, the differences between *A. potaninii* and *A. lobophylla* populations implies the ability of resistance and adaptation of *A. lobophylla* population to unfavorable condition is weaker than that of the *A. potaninii* population (Richard B. P.1997).

In this area, the relative favorable habitat for *A. lobophylla* population to live is only at altitudes 2700-3100 m. it is reasonable for us to assume that the area for *A. lobophylla* populations to live is narrow.

According to the result above, it is necessary for government to take action immediately to protect *A. lobophylla* population and the concerned vegetation, otherwise, the extinction of all populations is unavoidable.

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